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UARS MLS Observations of Lower Stratospheric ClO in the 1992-93 and 1993-94 Arctic Winter Vortex

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Abstract. UARS MLS measurements of lower stratospheric ClO during the 1992-93 and 1993-94 Arctic winters are presented. Enhanced ClO in the 1992-93 winter was first observed in early December, and extensively throughout the vortex during February when temperatures were continually low enough for PSCs. Sporadic episodes of enhanced ClO were observed for most of the 1993-94 winter as minimum temperatures hovered near the PSC threshold, with largest ClO amounts occurring in early March after a sudden deep cooling in late February. The observed behavior of enhanced ClO supports current understanding that processes triggered by PSCs activate stratospheric chlorine, and shows the amount of activation is highly variable in the Arctic vortex.

Introduction

The Microwave Limb Sounder (MLS) on the Upper Atmosphere Research Satellite (UARS) [Barath *et al.*, 1993] has now made measurements of O₃ and ClO, the dominant form of reactive chlorine that destroys O₃, through three Arctic winters. Waters *et al.*, [1993] describe MLS ClO measurements for the 1991-92 Arctic winter, with implications of lower stratospheric O₃ loss in January 1992 when ClO was greatly enhanced. Additional evidence of O₃ loss in the 1991-92 Arctic vortex has been presented [e.g., Browell *et al.*, 1993; Proffitt *et al.*, 1993; Salawitch *et al.*, 1993; Lefèvre *et al.*, 1994; Lutman *et al.*, 1994; Manney *et al.*, 1994a]. Manney *et al.*, [1994a] also analyze MLS measurements during the 1992-93 Arctic winter, and show substantial chemical loss of lower stratospheric O₃ during February and early March 1993 associated with enhanced ClO. Here we present the MLS 1992-93 Arctic winter lower stratospheric ClO observations in more detail, as well as those from the 1993-94 winter.

Data and Analysis

ClO and O₃ data used here are from the MLS 205 GHz radiometer, and in the MLS version 3 files on the UARS Central Data Handling Facility. Precisions (rms) of individual measurements at altitudes reported here are

~0.2 ppmv for O₃ and ~0.5 ppbv for ClO, with estimated absolute accuracies of 15-20% [papers in preparation by Froidevaux *et al.*, and Waters *et al.*].

Temperatures are from the US National Meteorological Center (NMC) analyses. Rossby-Byrtel potential vorticity (PV) is calculated from NMC geopotential heights and temperatures as described by Manney and Zurek [1993]. NMC temperatures are used in interpolations to isentropic surfaces. Vortex-averages are calculated as described by Manney *et al.* [1993], with estimated precisions of <0.05 ppmv for O₃ and <0.1 ppbv for ClO.

Results

Figure 1 shows time-series of vortex-averaged ClO and O₃, and minimum 465 K temperatures in the vortex, at 465 K potential temperature (~50 hPa pressure, ~20 km height). Data from all three northern winters for which MLS has observations are included, and show the strong interannual variability. Lower stratospheric temperatures in the 1991-92 and 1992-93 vortices dropped well below the threshold (~195 K) for polar stratospheric cloud (PSC) formation in mid-December [e.g., Manney *et al.*, 1994a]. A strong warming in 1991-92 [e.g., Manney and Zurek, 1993] raised minimum temperatures above 195 K by the end of January 1992. The 1992-93 minimum NMC temperatures remained below 195 K until a strong warming in late February [Manney *et al.*, 1994b]. The enhanced ClO in the vortex observed by MLS follows the pattern of minimum temperatures, as expected due to chlorine activation by processes on PSCs [e.g., Solomon, 1990].

Lower stratospheric vortex minimum temperatures in mid-December 1993 hovered about the PSC threshold, as they did at that time in the preceding two years. Near the end of December 1993 they rose above the threshold, but the vortex recovered after this warming and 465 K minimum temperatures again hovered around the threshold until late February [Manney *et al.*, submitted to JGR]. A sudden cooling occurred in late February, when the vortex strengthened and temperatures dropped well below 195 K for about two weeks until the beginning of the final warming.

Figure 2 shows maps of ClO during the 1992-93 winter for selected days from MLS north-looking periods (30 Nov - 8 Jan; 10 Feb - 18 Mar). Minimum temperatures were below 195 K for a few days in early December, and enhanced ClO was observed over Siberia in weak sunlight downwind from the region of lowest temperatures. Temperatures remained low enough for PSCs after about 26 Dec, but were located nearer the vortex center than in January 1992 and thus in a region of weaker winds and less sunlight. ClO abundances in early January were correspondingly less in 1993 than in

1992. When MLS north-looking resumed on 10 Feb, low temperatures were present near the vortex edge in a region of strong winds which experienced sunshine. The 10-24 Feb maps show the sunlit portion of the vortex was filled with enhanced ClO. As Arctic temperatures were continually below 195 K (Figure 1) while MLS was south-looking from 9 Jan to 9 Feb, we would also expect enhanced ClO throughout the vortex during this period. NMC temperatures generally rose above the PSC formation threshold around 24 Feb, and the enhanced ClO decayed during March.

Figure 3 shows maps of ClO during the 1993-94 winter for selected days from MLS north-looking periods (26 Nov-4 Jan; 511°E-14 Mar). Vortex temperatures were low enough for PSCs from about 18 Dec to 27 Dec (Figure 1). Most MLS high-latitude measurements in the early portion of this period occurred in darkness, but enhanced ClO was observed in weak sunlight and increased as orbit precession brought measurements into stronger sunlight. More ClO is seen on 2 Jan, although NMC 465 K temperatures were above the nominal PSC threshold by then, and the observed ClO decreased significantly by 4 Jan. Minimum temperatures at 465 K were slightly below 195 K during most of the MLS south-looking period. Significantly enhanced ClO was seen in the vortex at the beginning of north-looking measurements on 5 Feb, but at that time the temperatures rose above 195 K and ClO decayed during early and mid February - with a slight increase following the brief cooling below 195 K on 8 Feb.

Lower stratospheric temperatures in the vortex decreased abruptly around 22 Feb 1994, and the coldest period of the 1993-94 winter was 27 Feb - 3 Mar with minimum temperatures <190 K. ClO increased greatly following this cooling, and remained significantly enhanced during early March. The low temperatures during this period were well inside the vortex, and hence in a region of weaker winds than was the case when MLS observed enhanced ClO in January 1992 and February 1993. Although most of the vortex received sunlight during late February and early March 1994, the weaker winds at the location of low temperatures suggest less air was processed by PSCs than in January 1992 or February 1993. This is qualitatively consistent with our observations of the vortex not being so filled with enhanced ClO during the coldest periods of 1993-94 as in 1991-92 and 1992-93. The vortex generally warmed above 195 K around 11 Mar 94, and the ClO at 465 K had decayed considerably by 14 Mar.

Figure 1 shows that 465 K vortex-averaged O₃ increased during 5-27 Feb 1994, but decreased noticeably during early March. The vortex O₃ decrease during the time of enhanced ClO in early March 1994 suggests it is from chlorine chemistry, but more studies are needed

to clarify the effects of dynamics. This decrease is further discussed by Manney, *et al.*, [submitted to JGR] who analyze the evolution of O₃ and polar vortices for the three northern and two southern winters of MLS observations.

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Figure 1. Vortex minimum temperature (top), average ClO mixing ratio (middle: from the ‘day’ half of the orbit, but including measurements made in darkness at high latitudes) and average O₃ mixing ratio (bottom) at 465 K potential temperature for 1 Dec through 30 Mar during the northern winters of 1991-92 (green, thin), 1992-93 (blue, medium) and 1993-94 (red, thick). Large gaps in ClO and O₃ arc when MLS looked south; additional smaller gaps in 1993-94 arc due to MLS problems. The vortex boundary is defined here as the $2.5 \times 10^{-5} \text{ K m}^2 \text{ kg}^{-1} \text{ s}^{-1}$ contour of 1°V.

Figure 2. MLS maps of lower stratospheric ClO for selected days during the 1992-93 northern winter. The horizontal bar separates periods between which MLS looked south for ~30 days. Data arc from the ‘day’ half of the orbit, and have been interpolated vertically to 465 K potential temperature (~20 km height) and horizontally between measurement locations. The black contour locates where measurements were made when the sun was at 91° zenith angle (sza); here sunlight becomes weak and ClO decrease towards night is expected due to reduced ClO photolysis. Darkness occurs at ~94° sza for these altitudes, and the ‘night’ side of 91° sza is polewards of the black contour on all days shown here, except for 3 Mar when it was equatorwards (this varies due to orbit precession and inclination). Measurement local solar time and sza on a given day arc nearly constant around a latitude circle. The thin white circle concentric with the pole is the edge of polar night, and MLS measurements do not reach the white area polewards of 80°. Irregular white contours arc PV values of $2.5 \times 10^{-5} \text{ K m}^2 \text{ kg}^{-1} \text{ s}^{-1}$ (outer contour) and $3.0 \times 10^{-5} \text{ K m}^2 \text{ kg}^{-1} \text{ s}^{-1}$ (inner contour) which indicate the approximate edge of the vortex. Light violet contours indicate temperatures of 195 and 190 K (inner contour) when they exist. Occasional isolated values of high ClO can be artifacts caused by instrument noise.

enhanced ClO on 20 Dec over Russia was measured at ~94° sza and ~3:50 pm local solar time (just at sunset); enhanced ClO in this region was first observed by 19 Dec and persisted for several days.

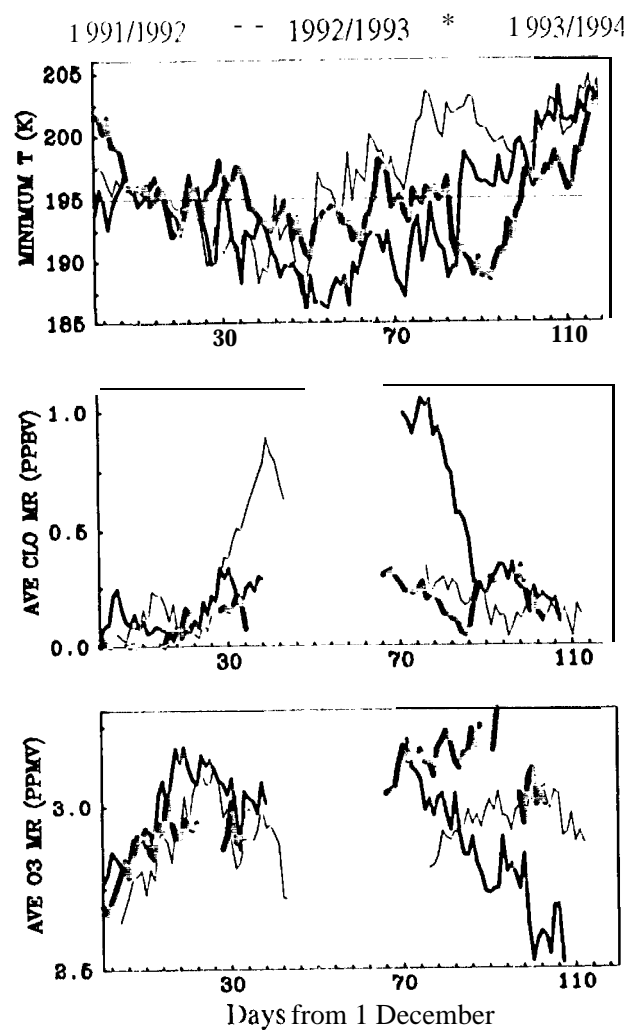


Fig 1

Lower Stratospheric ClO in 1992-93 NH Winter

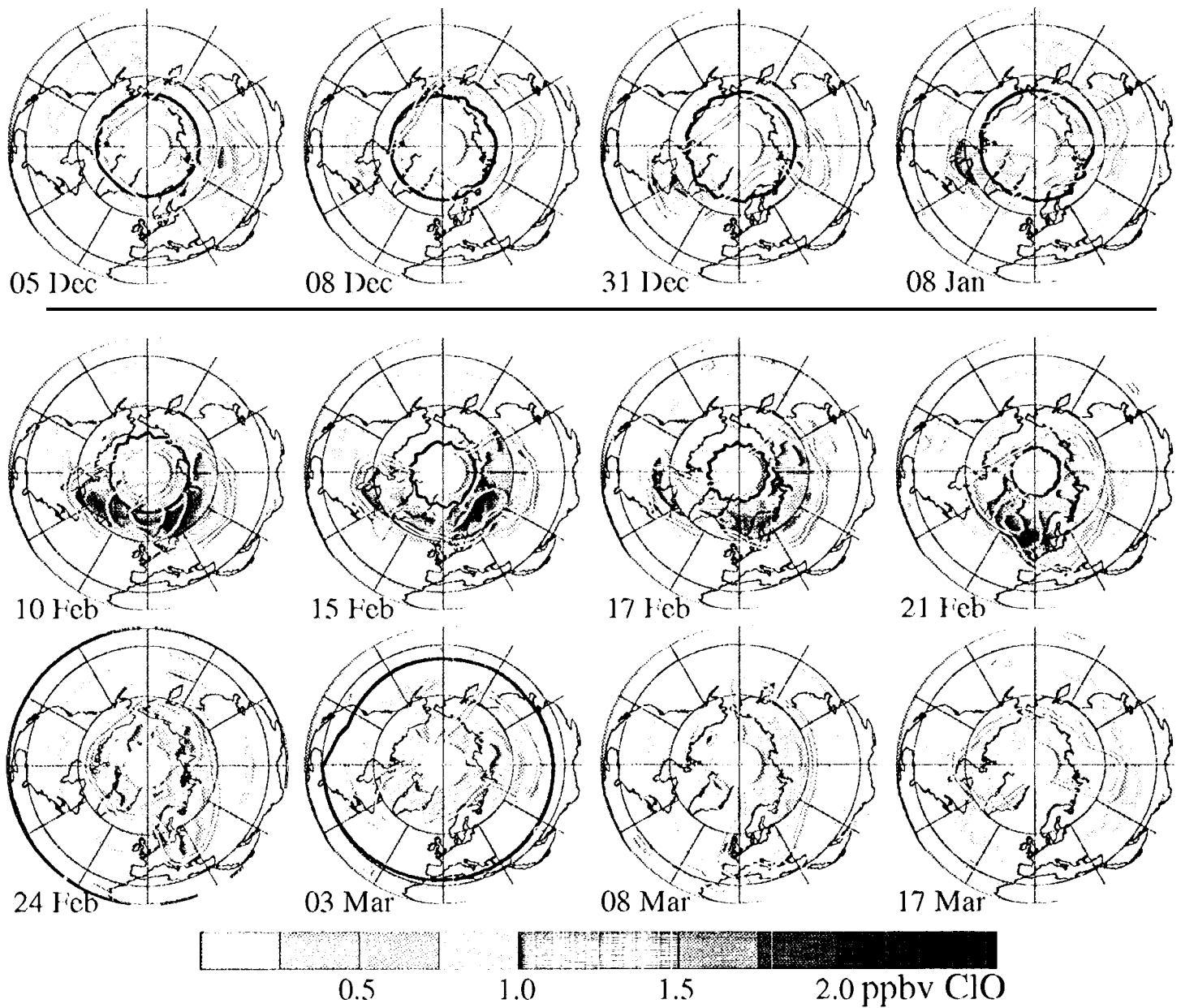


Fig 2

Lower Stratospheric ClO in 1993-94 NH Winter

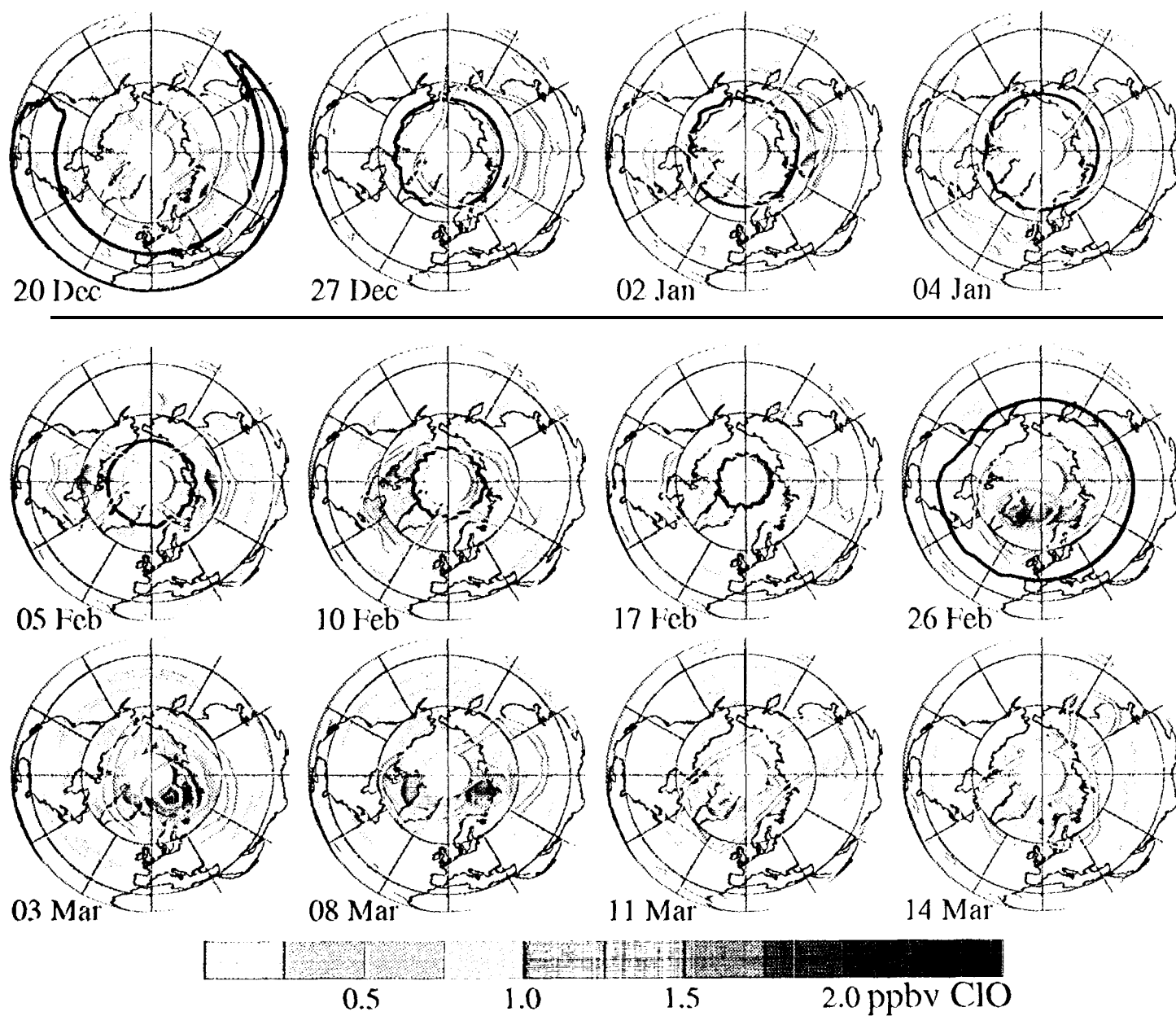


Fig 3